CHAPTER 24

INDUCTANCE IN a.c. CIRCUITS

It has previously been stated that inductance is a physical property and is not dependant on e.m.f. or current. The magnetic field produced by an inductor however does depend on current flow. In a d.c. circuit the current reaches a 'steady state' or constant value in a very short time after the current is switched on. During the time taken to reach the steady state condition there is a changing magnetic field and due to the inductance of the solenoid, there is a self induced e.m.f. in its conductors. Once the steady state current is reached, there is still a magnetic field around the solenoid but no self induced e.m.f. A self induced e.m.f. is only produced while there is a **changing** magnetic field.

24.1 DIRECT CURRENT AND VOLTAGE

When a direct current voltage is applied to an inductive circuit the current reaches a steady state condition in a very short period of time. The current then stays at a constant value flowing from positive to negative external to the source. A graph of direct current and voltage against time is shown in figure 24.1.

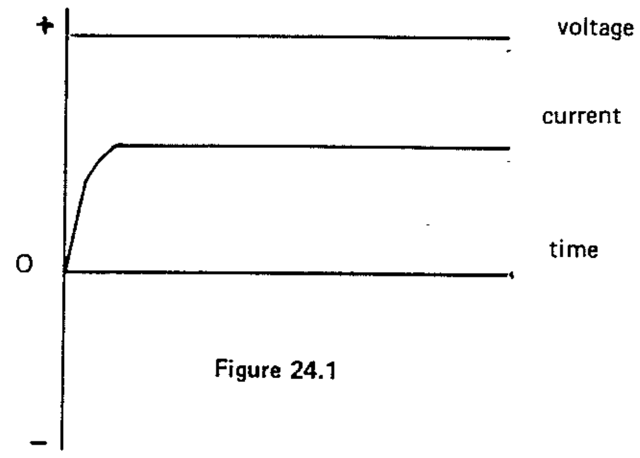

Figure 24.1

Some of the advantages of direct current are that because the current is constant the power drawn from the source is also constant. Also the value indicated by a d.c. meter is the maximum value reached by the voltage or current. Neither of these two facts apply to the alternative source of electricity called alternating current.

24.2 ALTERNATING CURRENT AND VOLTAGE

Direct current voltages and alternating current voltages can be produced by the same relative motion between a conductor and a magnetic field created by a pair of opposite polarity adjacent poles (Chapter 2, generators). Consider the conductor rotating through 360° in figure 24.2.

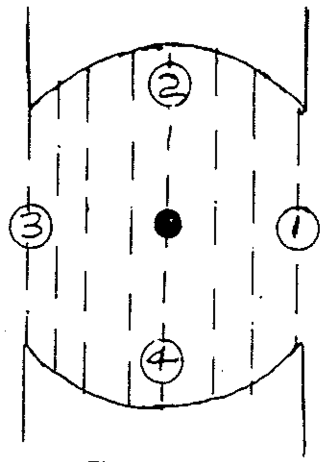

Figure 24.2

Using a horizontal axis marked in degrees and a vertical axis to represent induced e.m.f. a graph of the e.m.f. induced into a conductor as it rotated through 360° would look similar to that shown in figure 24.3.

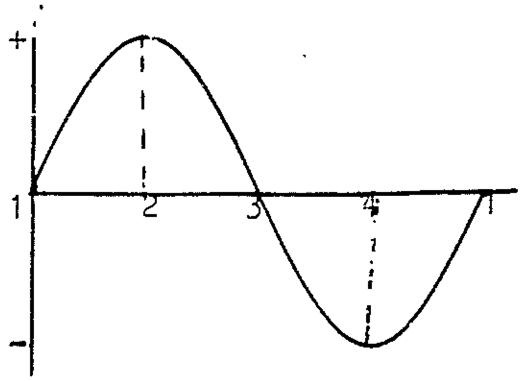

Figure 24.3

There would be zero induced e.m.f. at position No. 1 as the conductor is moving in the same direction as the lines of force. As the conductor rotated through 90°, position No. 2, the induced e.m.f. would increase from zero to a maximum because the conductor is now cutting the lines at a 90° angle (maximum induced e.m.f.). Using the same principles there would be zero e.m.f. after 180° (position No. 3), increasing to maximum induced e.m.f. at position 4 and decreasing back to zero on returning to position No. 1.

The resultant graph is known as an alternating current wave and is produced in both d.c. and a.c. generators. The basic difference between a d.c. and a.c. generator is that in the d.c. generator the alternating nature of the induced e.m.f. is converted into unidirectional current while in the a.c. generator it is connected directly to the generator terminals.

24.3 RESISTANCE ONLY IN d.c. AND a.c. CIRCUITS

In Chapter 4 it was stated that the opposition to current in any electrical circuit was called the impedance of the circuit. In a purely resistive d.c. circuit the current increases in the same proportion as the applied e.m.f. The only opposition to steady state current in a purely resistive circuit is the movement of electrons. The same applies in an a.c. circuit. Provided that the only impedance to current is resistance the current will change in direct proportion to the e.m.f., even though the e.m.f. itself is changing constantly. (Figure 24.4).

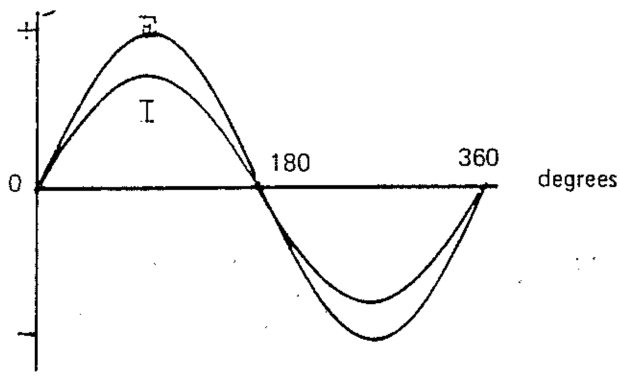

Figure 24.4

Because each alternating current wave passes through the horizontal axis at the same number of degrees from the zero point the voltage and current waves are said to be 'in phase'.

24.4 INDUCTANCE ONLY IN d.c. AND a.c. CIRCUITS

From previous statements it is seen that the inductive effect that produces a self induced e.m.f. in a d.c. circuit occurs only briefly while the steady state current condition is being reached. Current in an a.c. circuit is varying at all times so that if an alternating current voltage is applied to a solenoid the changing magnetic field is continually producing an induced or back e.m.f. From Lenz's Law the e.m.f. producing a current change is opposed by that current. A more simple way of expressing this is to say the current does not keep in step with the e.m.f. but lags behind the applied e.m.f. In a purely inductive circuit the current lags behind the voltage by 90°. (Figure 24.5).

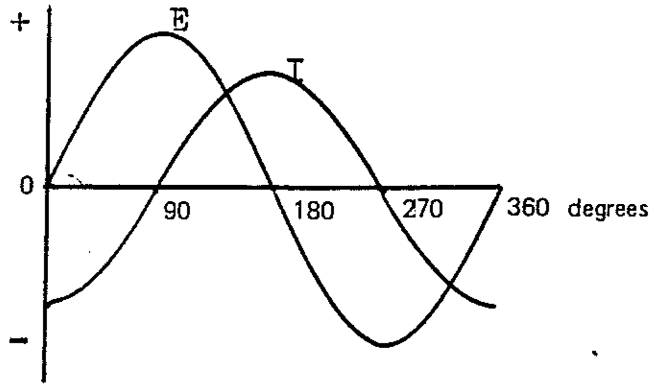

Figure 24.5

24.5 INDUCTIVE REACTANCE

The number of times the cycle of a.c. current occurs each second is called the frequency (f) of the a.c. supply. The unit for frequency is the hertz (Hz). A cycle of a.c. occurs when a conductor rotates 360 electrical degrees through a suitable magnetic field. (Figure 24.6).

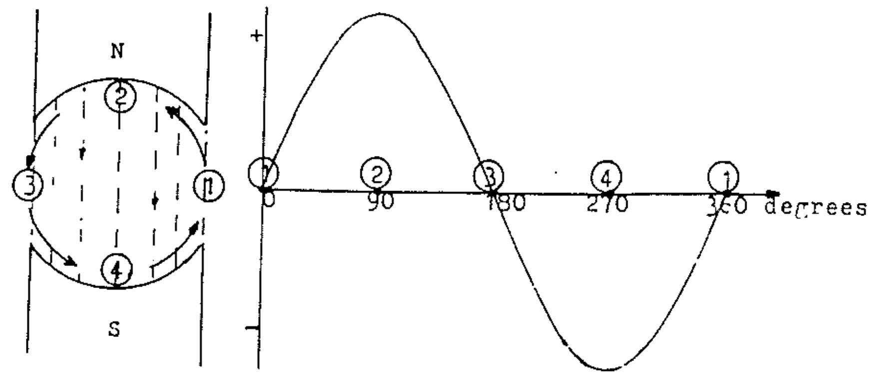

Figure 24.6

Three hundred and sixty degrees expressed as radians is equal to 2π. If the inductance of a circuit is equal to 'L' henrys then the total opposition to an a.c. current in a purely inductive circuit is equal to $2\pi \times f \times L$. This opposition to a.c. is known as inductive reactance because it reacts against the current change. Inductive reactance (symbol X_L) has the same units as any opposition to current, namely ohms.

$X_L = 2\pi f L$ ohms

Where

X_L = inductive reactance in ohms

f = frequency in hertz

L = inductance in henry

Example 24.1

Calculate the inductive reactance of a solenoid connected to a 50 Hz supply if the inductance of the coil is 0.1 henry.

f = 50 Hz

L = 0.1 H

X_L = ? Ω

$X_L = 2\pi f L$

$= 2\pi \times 50 \times 0.1$

$= 31.4\ \Omega$

Example 24.2

The inductive reactance of a solenoid is 50 Ω when it is connected to a 25 Hz supply. Calculate its inductance.

$X_L = 50\ \Omega$

$f = 25\ Hz$

$L = ?\ H$

$X_L = 2\pi f L$

$L = \dfrac{X_L}{2\pi f}$

$= \dfrac{50}{2\pi \times 25}$

$= 0.318\ H$

24.6 CURRENT IN A PURELY INDUCTIVE a.c. CIRCUIT

Ohm's Law implies that the current in any circuit is equal to the applied e.m.f. divided by the opposition to that current. This rule also applies to a purely inductive a.c. circuit.

$I = \dfrac{E}{X_L}$ amperes

Example 24.3

A coil having an inductance of 0.2 henry is connected to a 240 volt 50 Hz supply. Calculate the current drawn from the supply assuming zero resistance.

$E = 240\ V$

$L = 0.2\ H$

$f = 50\ Hz$

$X_L = 2\pi f L$

$= 2\pi \times 50 \times 0.2$

$= 62.8\ \Omega$

$I = \dfrac{E}{X_L}$

$= \dfrac{240}{62.8}$

$= 3.82\ A$

Example 24.4

A pure inductor draws 10 amperes when supplied from a 240 volt 50 Hz supply. Calculate the inductance of the coil.

$E = 240\ V$

$I = 10\ A$

$f = 50\ Hz$

$L = ?\ H$

$X_L = \dfrac{E}{I}$

$= \dfrac{240}{10}$

$= 24\ \Omega$

$X_L = 2\pi f L$

$L = \dfrac{X_L}{2\pi f}$

$= \dfrac{24}{2\pi \times 50}$

$= 0.076\ H$

Equations in this chapter

(1) $X_L = 2 \pi f L$

(2) $I = \frac{E}{X_L}$

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(1) A coil having an inductance of 0.2 H is connected to a 100 Hz supply. Calculate the inductive reactance of the coil.

(2) The inductive reactance of a coil was found to be 100 ohms when it was connected to a 50 Hz supply. Calculate its inductance.

(3) Determine the current drawn from a 240 V, 50 Hz supply by a purely inductive coil which has an inductance of 0.25 henry.

(4) A purely inductive coil draws 5 amperes from a 240 volt 50 Hz supply. Calculate the inductance of the coil.

(5) An inductor, which has an inductance of 0.1 henry, is connected to a 240 volt variable frequency source of e.m.f. Calculate the frequency of the source when the inductor draws 7.5 amperes.